Stretching Fat With Starch

Frederick C. Felker, Kenneth Eskins, and George F. Fanta

Blasting starch and oil with a steam jet yields a unique material with potential applications ranging from ice cream to seed coatings, hand lotions, and plywood adhesives.

What if . . .? As our minds are exposed to new ideas, materials, and information, occasionally we conceive of something radically different from anything else and wonder if it could be made. So it was that one of us, Kenneth Eskins, began to wonder some five years ago: What if I could make a synthetic cell and place in its membrane exactly the enzymes needed to make useful products? Furthermore, why shouldn't it be possible to make the cell membrane out of starch, a readily available agricultural product, instead of the rather specifically modified forms of fatty acids that comprise the membranes of most living cells?

Although research of this type had never been published, no one had proved that it couldn't be done. To tackle the project, Eskins, a chemist in the National Center for Agricultural Utilization Research (NCAUR) of the USDA's Agricultural Research Service in Peoria, Illinois, teamed up with another of us, George Fanta, who is an experienced carbohydrate chemist at NCAUR.

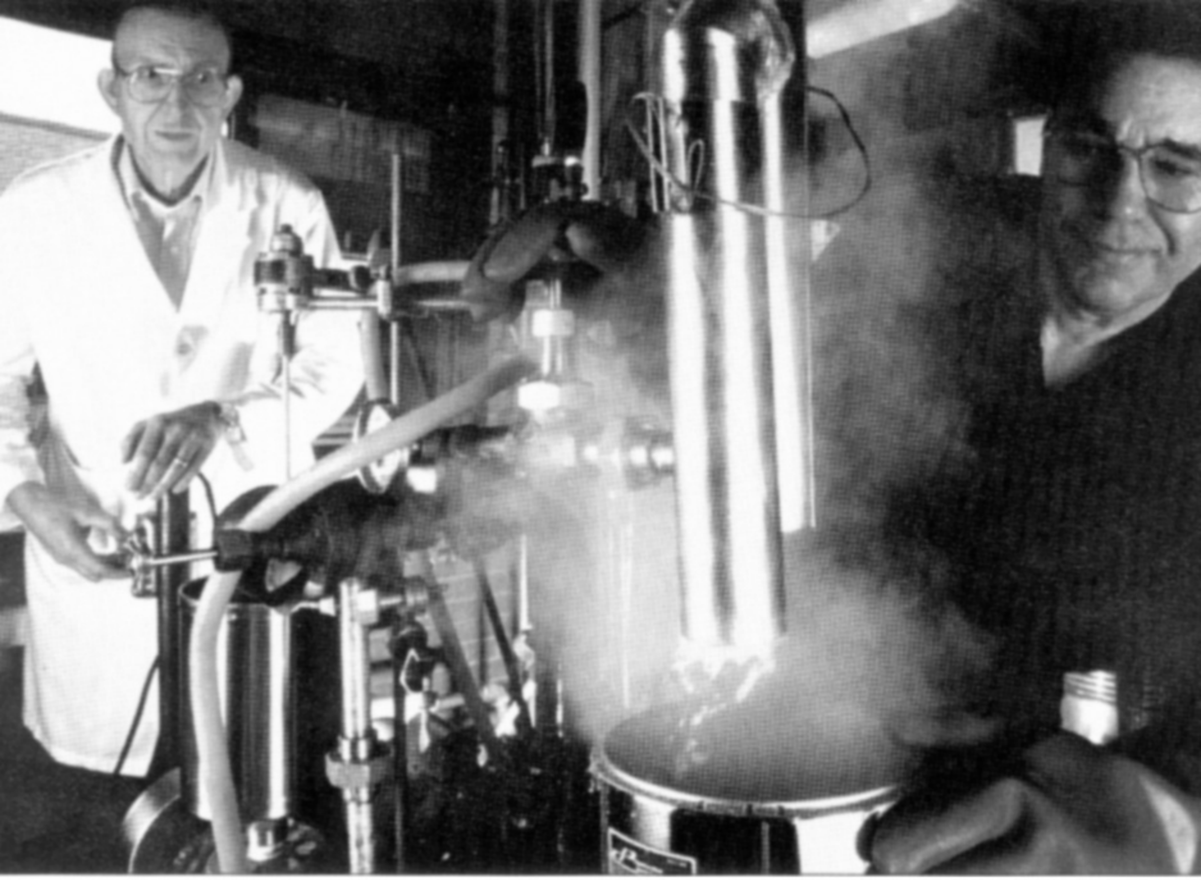
Their idea was to mix oil and starch "intimately" enough for individual starch molecules to interact with minute oil droplets. To achieve this, starch granules, which do not dissolve easily in water, would first need to be fully dissolved in it, so that the individual starch molecules would be uniformly distributed throughout the water. Then the oil would need to be broken into fine particles and mixed with the starch solution.

Fortunately, a technology that seemed likely to meet these two objectives was readily available in the steam jet cooker. By co-cooking starch and oil in the steam jet cooker, they reasoned, associations might form that could lead to membrane precursors.

To their surprise, they inadvertently discovered instead a kind of material that had never been seen before—one that was to evolve rapidly into an exciting new technology for transforming starch and oil into new products. The starch-oil composite formed in the steam jet cooker—tiny oil droplets surrounded by a film of starch and suspended in the greater body of starch—had remarkable stability and many unique properties, which will be discussed later. These products and the process for forming them have been granted the trademark Fantesk, one of only two trademarks owned by the USDA.

When the third of the authors, NCAUR plant physiologist Frederick Felker, joined the Fantesk team, he brought valuable expertise in microscopy, which was needed for characterizing the structure of the new materials. Felker determined the size and uniformity of the oil droplets formed under different cooking conditions. He also identified an oil-starch boundary layer that seems to be a key factor in giving Fantesk products their stability and other desirable properties.

What started out as one man's vision of a new artificial membrane system has evolved, with group effort, into the Fan-



■ Chemists George Fanta (*left*) and Kenneth Eskins process starch and oil together in superheated steam under pressure to form Fantesk, a new class of materials with a wide range of potential applications.

tesk process and family of products. Starting from the innovative idea of creating intimate mixtures of starch and oil, we have defined a broad type of process that is environmentally friendly and uses readily available agricultural products as starting materials.

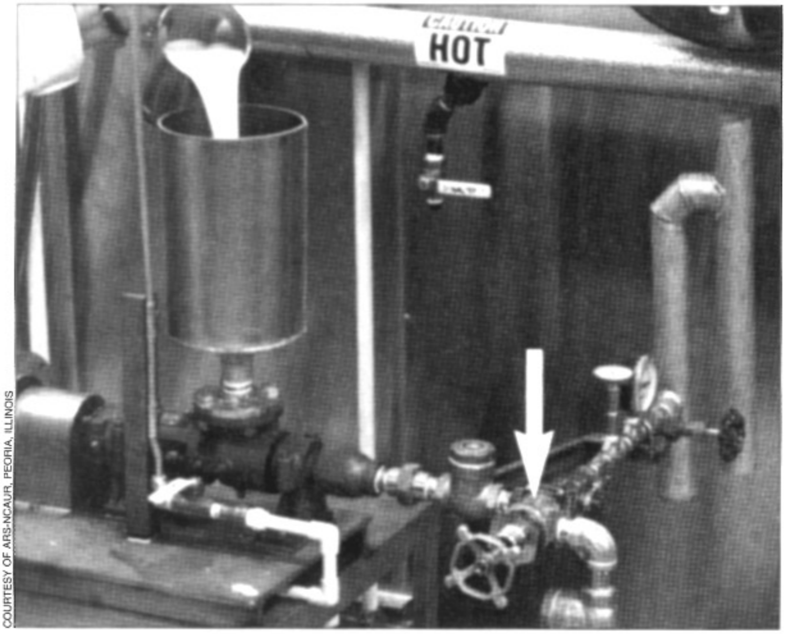
The diverse Fantesk products, each with the characteristic array of oil microdroplets encapsulated in starch, are themselves environmentally friendly and may find uses in products ranging from ice cream to hand lotion, face powder, popcorn, printer's ink, and plywood adhesives. The Fantesk process and products promise to generate new markets for major agricultural products and also to open a new scientific frontier: the study of the interactions of starch and oil on a molecular level.

Making the flakes

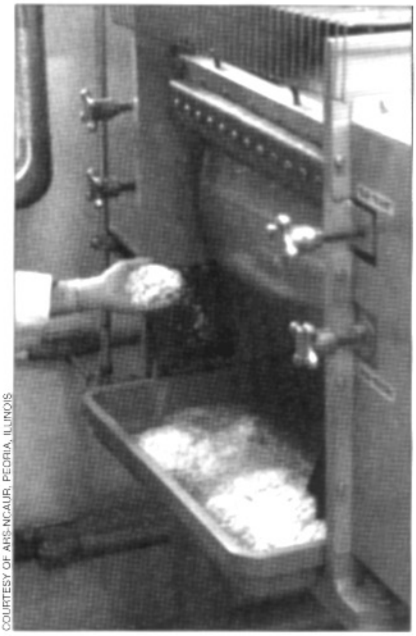
Cornstarch and soybean oil are among the highest-volume products of American agriculture, and an ever-increasing range of food and industrial applications is being developed for each of these. Rarely, however, have both substances been used together in the same application, since starch and oil are inherently incompatible. Within source plants as well, tiny oil droplets and starch only coexist at best, without the kind of intimate associations found in Fantesk products.

The broad class of Fantesk products is uniquely suited to carrying oil-soluble components into water-based systems or onto surfaces. In its liquid form, Fantesk is a stable suspension of microscopic oil droplets in a starch solution or gel and has the outward appearance of cooked starch but incorporates valuable properties of the oil forming the droplets. If made from normal cornstarch, the cooked dispersion will form a soft gel upon cooling. In contrast, if made from "waxy" cornstarch, it remains a liquid after cooling.

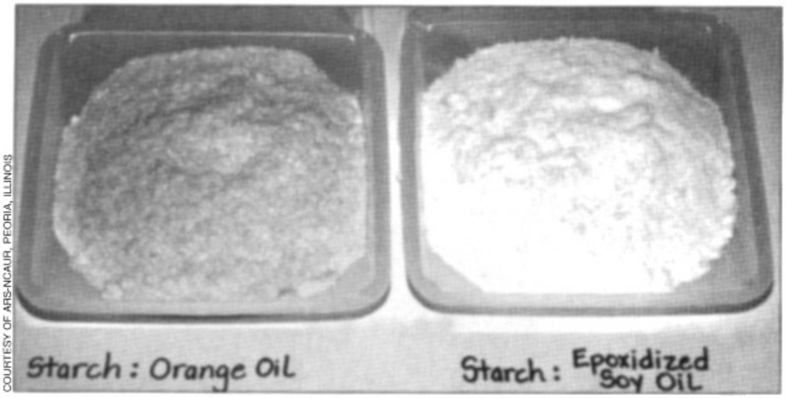
Oil droplets are usually with-



COURTESY OF ARS-NCAUR, PEORIA, ILLINOIS



COURTESY OF ARS-NCAUR, PEORIA, ILLINOIS



COURTESY OF ARS-NCAUR, PEORIA, ILLINOIS

■ *Above left:* **The hydroheater (arrow) is the steam jet cooker's center of action, where the mechanically mixed slurry of oil and starch (here being poured into the tank) is blasted by a jet of high-pressure steam. The resulting Fantesk liquid exits the collector tube at the right of the photo.** ***Above:*** **The Fantesk liquid is dried on the heated drum rollers shown here and scraped from the roller as flakes.** ***Left:*** **The flakes can be pulverized to form Fantesk powders, whose properties will vary, as is visually apparent here, according to the specific starting ingredients used.**

in the range of 1/10,000 to 1/100 millimeters (1/250,000 to 1/2,500 inch) in diameter. For comparison, the largest of the oil droplets would be only slightly larger than red blood cells, whose diameter is about 7/1,000 of a millimeter. Unlike the fat in whole milk, oil droplets in a Fantesk liquid or gel do not separate, coalesce, or cream to the top.

The liquid or gel product can be dried on steam-heated drums to yield flakes, which in turn can be milled to a fine powder that is dry to the touch, not oily. The oil is encapsulated as microdroplets within the dried starch powder. Fantesk powder can be used directly as a dry ingredient, or it can be easily mixed with hot water to reconstitute the original liquid or gel product at any desired concentration. The liquid can be applied to many kinds of surfaces and then dried as a thin film that adheres to the surface. This versatility, which makes so many diverse applications possible, is one of the most important aspects of the technology.

Steam jet cooking

The unique approach of the Fantesk method is to physically blend a quantity of oil into the starch granule slurry immediately before (or after) passing it through a steam jet cooker and to maintain a high level of mixing long enough for the starch

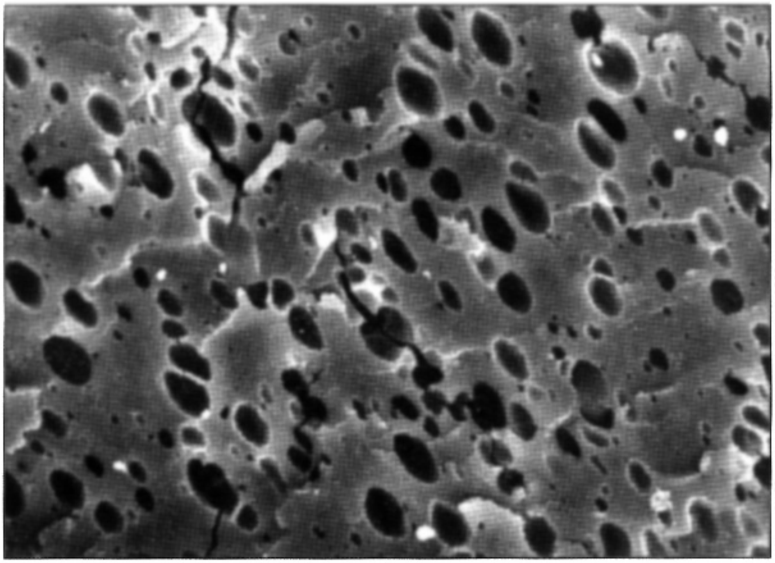
Unlike the fat in whole milk, oil droplets in a Fantesk liquid or gel do not separate, coalesce, or cream to the top.

molecules to surround the oil droplets.

Once the mixture of oil in the starch granule slurry enters the steam jet cooker, turbulence keeps the mixture from separating until it is blasted by a powerful jet of steam that cooks and breaks up the starch granules while homogenizing the oil into a population of microscopic droplets. Alternatively, fats or oils could be blended in after jet-cooking the starch separately.

For those applications in which a viscous liquid or soft gel is required, the product can be used or packaged directly after it emerges from the jet cooker. Alternatively, a free-flowing dry powder can be produced by drum drying and milling, using commercially available equipment. Since starch is good food, even for microorganisms, standard practices of aseptic food handling must be used. Preservatives can also be included in the formulation if necessary.

Mixing the dried powder with water easily reconstitutes the liquid or gel form, which has basically the same properties as the freshly cooked composite. Drying the gel to a powder at the point of manufacture and reconstituting it at the point of use provides an efficient means of preserving and transporting the essential starch and oil components without the bulk of the replaceable water component.



FREDERICK FELKER / COURTESY OF ARS-NCAUR, PEORIA, ILLINOIS

■ **Removal of the microdroplets of oil from a Fantesk film leaves a starch film pockmarked with cavities vacated by the oil droplets, as shown in this electromicrograph. The largest holes are slightly larger than red blood cells.**

A closer look

Microscopic analysis of Fantesk in any of its diverse forms reveals separate starch and oil phases not discernible to the naked eye. One way of determining the distribution of the oil is to air-dry a liquid Fantesk product so that it forms a starch-matrix film. If a small piece of the film is then broken off and rinsed with hexane or ethanol to remove the oil, scanning electron microscopy reveals a distinct pattern of holes corresponding to the oil droplet distribution.

By using light microscopy it is possible to measure and count the oil droplets in water dispersions of Fantesk. Also, various stains can be used to identify and visualize specific components such as starch and added proteins.

Additionally, Fantesk in a gel form can be cut into tiny blocks (about 1 cubic millimeter), processed, and embedded in a resin for thin sectioning. With this

Fantesk Chemistry

Starch, an energy-storage molecule made by plants, is a high-molecular-weight polymer composed of thousands of units of glucose, the most basic sugar. Typically starch molecules are a mixture of linear and branched components that curl up and bind with other starch molecules to form granules. The linear component, amylose, has a molecular weight of several hundred thousand, while the branched component, amylopectin, weighs in at several million. Normal cornstarch is about 25 percent amylose and 75 percent amylopectin, but a mutant type of corn called "waxy" produces a starch that is essentially all amylopectin.

Plants deposit starch in the form of insoluble granules in their seeds, roots, and stems. These granules range in size from 5/1,000 up to 40/1,000 of a millimeter, which places the largest granules at nearly equal to the diameter of a hair. Granular starch remains unchanged when added to water until the temperature is raised to about 150°F (66°C), at which temperature the granules swell and gelatinize. More heat plus mechanical shear is required to dissolve the starch in water. Steam jet cookers provide just the right amount of heat and shear.

Even after starch has been dissolved in water, its straight-chain amylose component readily reassociates, forming first crystalline domains and then a gel as the solution cools. In contrast, the branched-chain amylopectin component by itself does not crystallize or gel to any appreciable extent as it cools. Thus, simply by balancing the proportions of these two different starch components, scientists can customize the texture of the cooked Fantesk product.

Oils and fats have a more diverse chemistry than starch, but as a group they do not mix with water at all. Fantesk disperses the oil into droplets with sizes suitable for many applications, but it avoids the separation or coalescence of the oil phase.

—F.C.F., K.E., G.F.F.

technique, which is similar to that used for microscopy of plant and animal tissue samples, both high-resolution light microscopy and transmission electron microscopy can be used on the same sample for more detailed observations.

To track the fate of a Fantesk material as it is involved in a particular application, both the starch component and the oil droplets can be stained with specific dyes whose colors can be detected either by ordinary photography or by light microscopy as the starch and oil interact with other ingredients.

Fantesk's family of applications

Low-fat foods and fragrances. One of the first applications of Fantesk technology envisioned was as a fat replacer in foods. The material's lubricity and feel in the mouth is very similar to that of fats and oils. Also, even though the oil component comprises only a small fraction of the liquid or gel, it imparts flavor by carrying oil-soluble flavor components into the aqueous phase.

Puddings, ice cream, baked goods, and ground meat products are natural candidates for using Fantesk to replace fat. As an example, a butter flavor can be added to soybean oil, and a Fantesk liquid that is very low in oil can be applied as a film coating to popcorn. When the popcorn is popped in a microwave oven, the butter flavor permeates the corn with insignificant added fat. In this case the small oil-droplet size favors the spread of flavor components very uniformly over a large area, and the large surface area promotes the outward diffusion of flavor and aroma constituents. Similar effects were obtained with ice cream and ground beef.

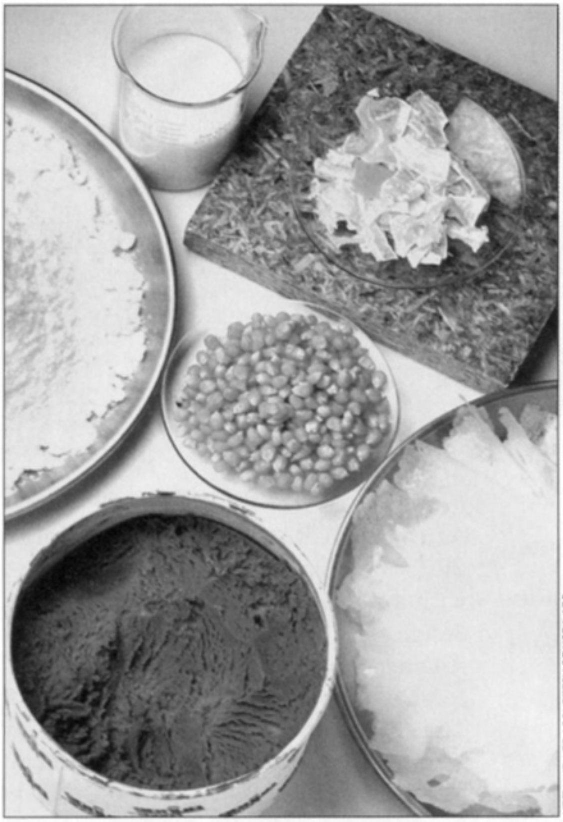
The encapsulating feature of Fantesk can be demonstrated with fragrance oils. Sweet orange oil or limonene, for example, can be incorporated into Fantesk films and powders that will retain the scent for long time periods.

Targeting agricultural chemicals to the seeds themselves is a powerful strategy for protecting the environment.

Fragrance oil trapped within the starch matrix is not free to evaporate until the matrix is disrupted by breaking or crushing the product.

While these applications have all been demonstrated in the laboratory, and several different food processing companies have experimented with Fantesk materials, none have yet reached a binding public agreement with the USDA for developing the food-related applications. The USDA is actively seeking partners to help commercialize this technology.

Seed film coatings. Agricultural applications of Fantesk are best exemplified by the development of seed coating applications. Many types of pesticides are poorly soluble in water and could be more easily dissolved in an oil-soluble nonaqueous carrier. Because Fantesk products are a microdispersion of oil in starch, they can be used for targeted delivery of oil-soluble pesticides to the surface of seeds. Already, Fantesk products formulated with specific waxes, resins, plasticizers, and cross-linking agents have proved effective as film coating materials for beans.



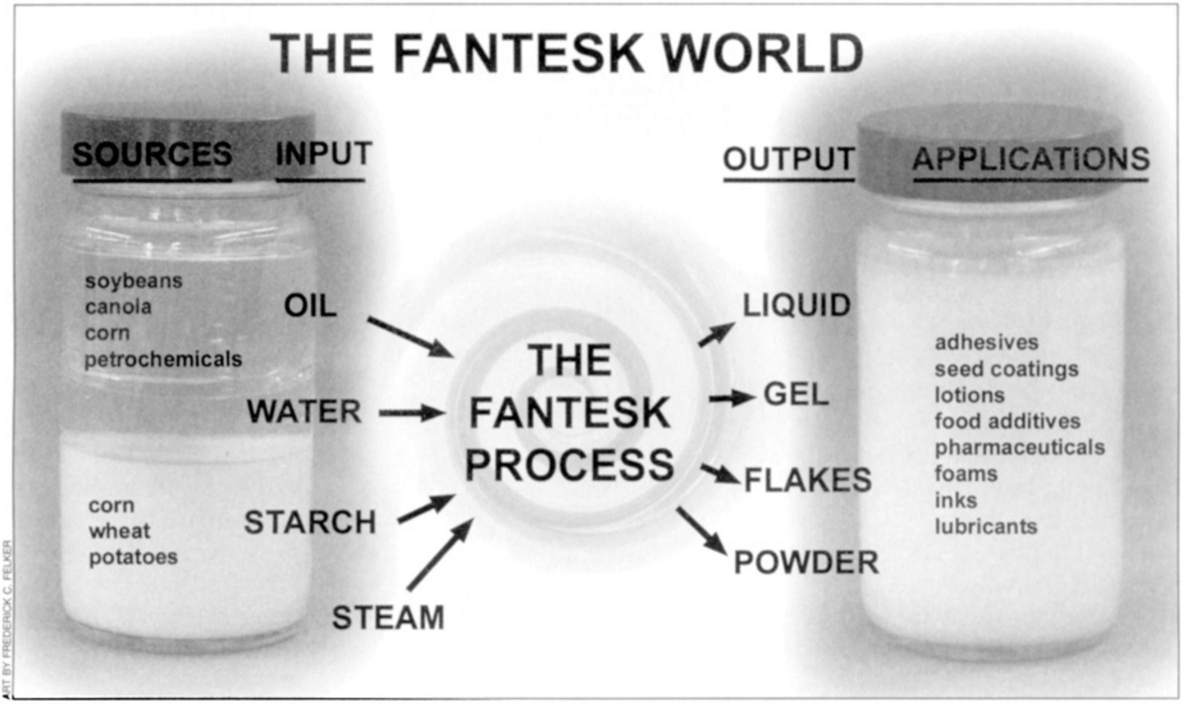
KEITH WELLER / COURTESY OF USDA-ARS

■ The diverse potential applications of Fantesk range from a fat substitute in ice cream to coatings on seeds to an adhesive for particle board. The diverse forms of Fantesk products are (*clockwise from top left*) powder, gel, flakes, and film.

An additional advantage of coating seeds with Fantesk film is that it slows down the seed's water uptake, which enhances germination and seedling survival in cool or wet soils. This physiological advantage clearly raises the commercial value of the seeds.

Furthermore, targeting agricultural chemicals to the seeds themselves is a powerful strategy for protecting the environment. In contrast, when these chemicals are disseminated on the soil, the amount required to have a desired effect is several orders of magnitude higher than when they are targeted to the seeds. Seed-targeted agents can diffuse from the seed to the immediate environment of the developing root zone, and the vast spaces between individual seeds need not be supplied with the chemicals, which often only leach into the soil and present environmental problems.

In addition to pesticides, plant hormones and nutritional additives such as fertilizers can be incorporated into the seed coating. Increasingly important in agriculture is the emerging technology of biological control, whereby beneficial microorganisms are used to fight specific pathogens. Here, too, Fantesk's seed-targeted



■ In tomorrow's Fantesk world, the Fantesk process will be used to custom-make a variety of materials, each suited for a specific application, ranging from adhesives to lubricants. The process readily accommodates starch and oil inputs from diverse sources.

delivery holds advantages over conventional dispersal technologies. Fantesk provides a basis for coating seeds with a layer that incorporates ingredients to protect, nourish, and disperse beneficial microorganisms.

Two of the scientists on the Fantesk team have a background in plant physiology, so they were well prepared to work on extending the technology to seed coatings. They worked closely with scientists from a seed coating company under a Cooperative Research and Development Agreement (CRADA) to fine-tune the formulation, and also worked with a machinist at NCAUR to design and construct a large-scale steam jet cooker.

Foams, glues, and more. The Fantesk process can be applied to a wide variety of starches and gums; similarly, it can accommodate diverse types of lipid materials such as oils, fats, waxes, and resins. This makes a broad range of specific industrial applications possible, as ongoing research has demonstrated.

For example, adhesive applications such as glues for making particle board and plywood have been investigated through CRADAs with different companies. Several publications have described the use of Fantesk products to modify the cell structure and water permeability of polyurethane and polyester foams.

Among the powerful points attracting industrial attention to the Fantesk process, three stand out:

- The process permits the use of low-cost ingredients in manufacturing products, so they can be made more cheaply.
- The properties of many products can be improved by the microencapsulation feature of the Fantesk process.
- With this starch-oil technology, the products are completely biodegradable.

Products like agricultural foams for soil applications, oil-drilling muds, water-based lubricants, cardboard coatings, and paint removers are but a few of the many possible high-volume applications that scientists are

Extremely promising is the use of Fantesk's starch-encapsulated oil droplets for delivering drugs to target sites in the body.

just beginning to explore.

Cosmetics and pharmaceuticals. The simplicity and safety of the basic ingredients and the absence of chemical emulsifiers makes the Fantesk process an important new entrant in the fields of both cosmetics and pharmaceuticals. Cooperative research with companies interested in beauty and health-care products is in progress. Lotions, creams, and other types of products are readily prepared by steam jet cooking, and the choice of additive ingredients for enhancing value is enormous.

In one instance, a water-insoluble drug was successfully formulated into Fantesk with specific types of starch and lipid carriers. Cooperative research with a medical school pharmacology team showed promising bioavailability and pharmacological effectiveness in experimental animals. Because all the nondrug ingredients are on the GRAS (generally recognized as safe) list, we expect FDA approval of such drug delivery systems to be less difficult than for competing technologies.

Actualizing the potential

Our small research group at NCAUR was quickly spread thin in its efforts to identify Fantesk's many commercial possibilities. Fortunately, the Agricultural Research Service encourages technology transfer to expedite the commercial application of federally funded research so as to benefit the public.

The primary mechanism for transferring technology from a government research facility to the commercial sector is the Cooperative Research and Development Agreement (CRADA), established between the sponsoring government agency and a private enterprise. Through agreements of this type, researchers from the government facility and from industry share their resources and research results as they strive to solve such problems as how to adapt a new technology to a commercial product and how to scale up manufacture of the commercial product. Several Fantesk-based CRADAs, covering a variety of applications, are either in place or under negotiation.

The first Fantesk-based product to reach the market is likely to be Fantesk-coated seeds.

In the middle range of development (with CRADAs either in place or under negotiation), but needing up to several years to reach the market, are the bulk of the Fantesk applications, including adhesives, health-care products, insulating foams, and industrial lubricants. More exploratory but extremely promising is the use of Fantesk's starch-encapsulated oil droplets for delivering drugs through the bloodstream to target sites in the body.

Somewhat surprising is the laggard position of the food applications, where the potential of Fantesk materials as a low-fat but flavorful additive is so promising and well demonstrated. For the moment, no food processor is seriously looking at using the technology.

From a single discovery made by two scientists exploring beyond the bounds of scientific convention, Fantesk technology is growing into a family of diversified products. The family is so young that its members have scarcely moved beyond the laboratory walls, yet few who know about it doubt that this family will move boldly onto the world stage in the twenty-first century. ■

Frederick C. Felker is a plant physiologist at the National Center for Agricultural Utilization Research (NCAUR) of the USDA's Agricultural Research Service in Peoria, Illinois. Also located at the NCAUR are Kenneth Eskins, a chemist in the biomaterials processing research unit, and George F. Fanta, a chemist in the plant polymer research unit.